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TELEMETRY DATA PROCESSING FOR THE ECCENTRIC ORBITING GEOPHYSICAL OBSERVATORY SATELLITE

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R. Coates, C. Creveling, E. Habib,
M. Mahoney, and C. Stout

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Summary

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The Eccentric Orbiting Geophysical Observatory (EGO) is being designed to have PCM telemetry data rates of 1000, 8000, or 66,000 bits/second - selectable by ground command. This satellite will have on-board data storage for low speed data (1000 bits/second) plus about 40 percent ground station coverage of each orbit for data acquisition at any of the bit rates. The program planned for the first EGO satellite anticipates receiving an average of 6000 bits/second for a period of six months, or a total of about 10^{11} bits. The high speed data processing system for this high volume of data consists of two processing lines plus a large scale digital computer. The processing lines convert the analog recordings of the PCM telemetry signals to digital magnetic tapes in computer format. The computer then performs quality control and decommutation of the data into separate digital tapes for each experimenter. The system will be described in detail.

AUTHOR

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INTRODUCTION

The Eccentric Orbiting Geophysical Observatory Satellite[1] (EGO) is the first of a series of large satellites designed to accommodate a variety of scientific space experiments. These satellites will be placed into orbit at regular intervals over the next several years. By their size and complexity, and by the number of experiments aboard (20 in the first EGO), these satellite projects have called for a fresh look at the problems of telemetering to earth vast quantities of data, and of processing this data into forms suitable for utilization by the experimenters. In order to appreciate these problems, a few statistics are in order.

The telemetry system of the EGO satellite provides many modes of operation in order to handle a variety of data types and provide sampling rate flexibility. The main telemetry system is a PCM system with a basic format of 128 nine-bit words in the main frame. In the real time mode, data can be telemetered at a rate of 1000, 8000, or 64,000 bits/sec as selected by command. This permits selection of the data rate

[1] W. E. Scull and G. H. Ludwig, "The Orbiting Geophysical Observatories," Proc. IRE, Vol. 50, pp. 2287-96, Nov. 1962

which best matches the needs of the experiments at the particular time of observation. In addition to the choice of basic bit rate, provision is made for command selection of two special modes of operation to provide certain data at accelerated sampling rates.

In the first special mode, the normal main frame is replaced with one of 32 combinations of outputs from several specified experiments. This flexible format mode enables a subgroup of experiments to be operated when phenomena of special interest occur. In the second special mode, one of the spacecraft sub-commutators may be substituted for experimental data in order to obtain more operating and functional data relating to the spacecraft itself.

Continuous on-board recording at a rate of 1000 bits/sec is provided by two tape recorders with a capacity of 43.2 million bits each. The recorded data are played back on command at a rate of 64,000 bits/sec.

In addition to the PCM system, a special purpose FM/PM telemetry system is provided for transmission of continuous analog data which cannot be time multiplexed into the PCM system.

The telemetry signal from the EGO satellite will be received at ground stations, demodulated, and recorded on magnetic tapes. These tapes will be mailed to the Goddard Space Flight Center's data processing facility for production processing. The amount of data to be acquired from EGO is estimated in Table 1.

Table 1
ESTIMATED EGO DATA ACQUISITION

	PCM			Special Purpose
	64,000 b/s	8,000 b/s	1,000 b/s	
NORMAL				
a. First Month	10%	30%	100%*	40%
b. Rest of EGO Life	5%	20%	100%*	25%
ALERT				
a. Entire EGO Life	0.5%	6%	--	--

*Using the on-board tape recorder.

In six months, a total of about 10^{11} bits of data will be acquired from this satellite. This large volume of data will be processed at the Goddard facility on data processing systems consisting of signal conditioning and formatting units plus a large scale digital computer. These processing systems will extract the telemetry and ground station time signals from the station tapes, write this raw data on digital tape in computer format, fan out the data to produce a digital tape for each experiment (containing the data for the experiment plus supporting spacecraft data), generate an orbit-attitude digital tape, and convert spacecraft time to universal time.

PCM DATA PROCESSING

The telemetry tapes received from the data-acquisition stations will be logged and the contents of the tapes will be examined to determine their quality, whether or notthe signals were recorded on the proper track, the presence of usable time signals, and whether there may be an equipment malfunction at the data-acquisition station. This tape evaluation provides feedback to the stations in addition to separating tapes which cannot be processed in the automatic system.

The processing of the PCM data on the acceptable station tapes can be described in four phases. Phase I will use specially designed processing equipment while Phases II, III, and IV will use a Univac 1107 digital computer.

The Phase I system (as outlined in Figure 1) is based upon the STARS (Satellite Telemetry Automatic Reduction System[2]) concept of initial digitization of the data to produce a digital tape in proper format for entry into a computer. The soundness of the STARS concept has been established by two years of processing of PFM data from numerous Goddard scientific satellites. These, however, utilized far lower data rates than EGO and similar "observatory" class satellites. The design of the EGO Phase I processing system contains many improved features for the faster and more efficient handling of the large volume of EGO data.

A pair of analog tape decks are used alternately for playback of the station tapes. The serial PCM signal (which will be very noisy when

[2] C.J. Creveling, C. Stout, A. Ferris, "Automatic Data Processing," IRE Trans. Vol. SET-8, No. 2, June 1962.

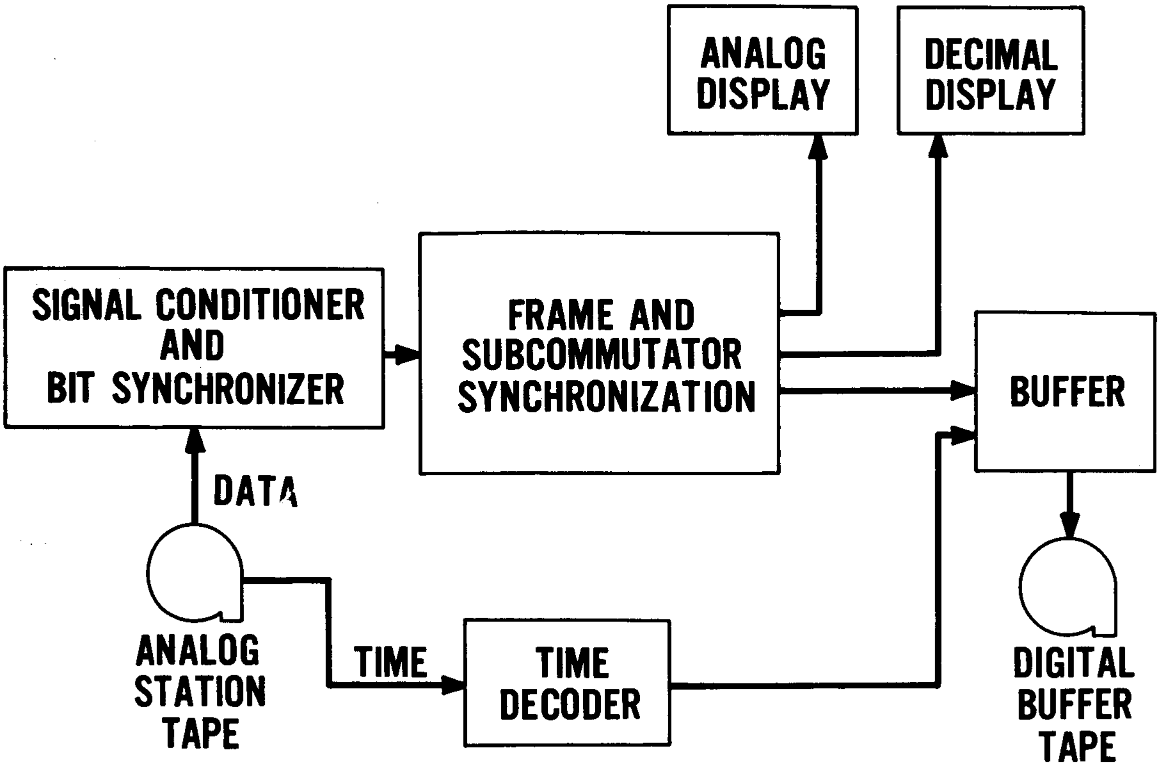


Figure 1–Production Data Processor for EGO – Phase I

the satellite is at apogee) is routed to the signal conditioner, and the ground station time codes and reference frequencies are sent to the time decoder. The signal conditioner generates a "clock" signal synchronous with the incoming bit rate, decides whether each bit is a "one" or a "zero," and reconstructs a noise-free PCM signal with the same structure as the input PCM signal. The data from the signal conditioner is shifted into a 32-bit shift register via a code converter. This shift register is also used as a serial-to-parallel converter, from which the data is distributed in parallel form to appropriate units in the processor. The frame and sub-commutator synchronization recognizers continuously check the incoming data for the presence of frame and subcommutator synchronization patterns respectively. Immediately upon recognition of the proper patterns, the frame and subcommutator synchronization circuits are "locked" and the decommutation process is initiated. By having several decommutating units in the processor, decommutation of multiple subcommutation sequences randomly located in the main telemetry frame is made possible. The synchronization patterns are selectible by means of a patchpanel. For EGO, a 27-bit truncated autocorrelation code is used. The frame synchronization circuitry offers "flywheel" capability when frame synchronization is lost due to data dropout. It determines the number of errors in the frame synchronization pattern and remains in "lock" as long as the errors do not exceed a preset number (selectible between 0 and 5). When the number of errors is larger than the allowed number for several successive synchronization detections, data to the buffer is deleted and the circuit reverts to a "search" mode. This mode (also used during the initial period of processing a tape) looks for the synchronization pattern each "clock cycle," thus effectively determining the cross-correlation function of the signal with the stored frame synchronization pattern. When in synchronization, this function exceeds the amount preset in the "synchronization errors allowed" counter. After a few successive synchronization recognitions, the circuit proceeds to the "lock" mode and processing begins or continues. The actual error count in the frame synchronization word is provided to the buffer and interleaved with the data as an indication of data quality. The frame and subcommutation formats are selectible in order to handle the several classes of data that will be processed. For example, real-time data will be recorded at either 8 or 64 kilobits/sec in the standard or the special modes, and the data recorded on the spacecraft will be played back to the data-acquisition stations in reversed time sequence. Each of these classes require different frame and subcommutation format programs during the Phase I processing, so that the buffer tape created as an end result of the Phase I operation will contain the data in a uniform format.

Decimal and analog displays are provided for a "quick look" at the incoming data and synchronization patterns. Information in particular frame locations can be read out directly to check the quality, validity, and proper decommutation of the acquired data before reduction in subsequent phases.

The synchronization information and the data are entered into the buffer memory and control circuitry where the data are merged with time readings and written on digital tape in high density IBM computer format (556 characters per inch).

The readings of the acquisition station time are provided to the buffer by the time decoder unit. The time decoder receives three signals from the station tape. The stations record the NASA binary coded decimal (BCD) time code[3] and the NASA serial decimal (SD) time code

[3]Hewlett Packard Applications Note 52, pp. 1-6, Jan. 1962

from the station time standard plus a standard frequency. Since the tapes are played back at higher speeds in the processing operation than used in recording, the time decoder is designed to accept time signals with speed-up ratios of 1, 2, 4, 8, and 16. A BCD code detector reads the BCD time code and a SD code detector reads the SD time code. Each decoded time is displayed for the operator. An internal 1 Kc oscillator is phase locked to the incoming standard frequency through divider chains. The time, as decoded in either the SD or BCD decoders, is automatically set into the accumulating register at the beginning of each processing run or when the mode of operation changes. This register is updated by the 1 Kc output from the internal oscillator. A comparison is made between the next BCD time reading, SD time reading, and the updated time in the accumulator. These will agree under normal circumstances, and a quality "flag"* indicating agreement will be presented to the buffer together with the time word from the accumulating register. If the BCD or SD times do not agree with the accumulator, this is also flagged. When the time readings disagree, the circuits automatically check themselves for malfunction. If there is no circuit malfunction, a determination is made as to whether or not the BCD circuit is in synchronism with the incoming BCD time code. If it is in synchronism, a new BCD time code is set in the accumulating register and updated. Thus, when there is a break in the data acquisition period, the time decoder automatically picks up the new time at the start of the new period. The time decoder will flywheel through momentary time signal dropouts or time code errors because the internal oscillator keeps updating the accumulator. If there is a BCD circuit malfunction or a loss of the signal, the BCD circuit is inhibited and the SD circuits provide the time reading. The reverse is true if the SD system fails. Thus, the decoder makes use of the redundancy of having both the BCD and SD time signals available for processing. If only one of these two signals is present, it automatically considers only that one. The "flags" included with each time reading sent to the buffer indicate the amount of confidence the experimenter can place on its accuracy.

The buffer tape produced as an output of Phase I will contain all the raw data, acquisition station time, and status information concerning time and the condition of bit, frame, or subcommutator sequence synchronization. The buffer tape format will be such that the raw data from each telemetry frame will have associated with it a time field and a status field, as shown in Figure 2.

*The time quality flag consists of two characters.

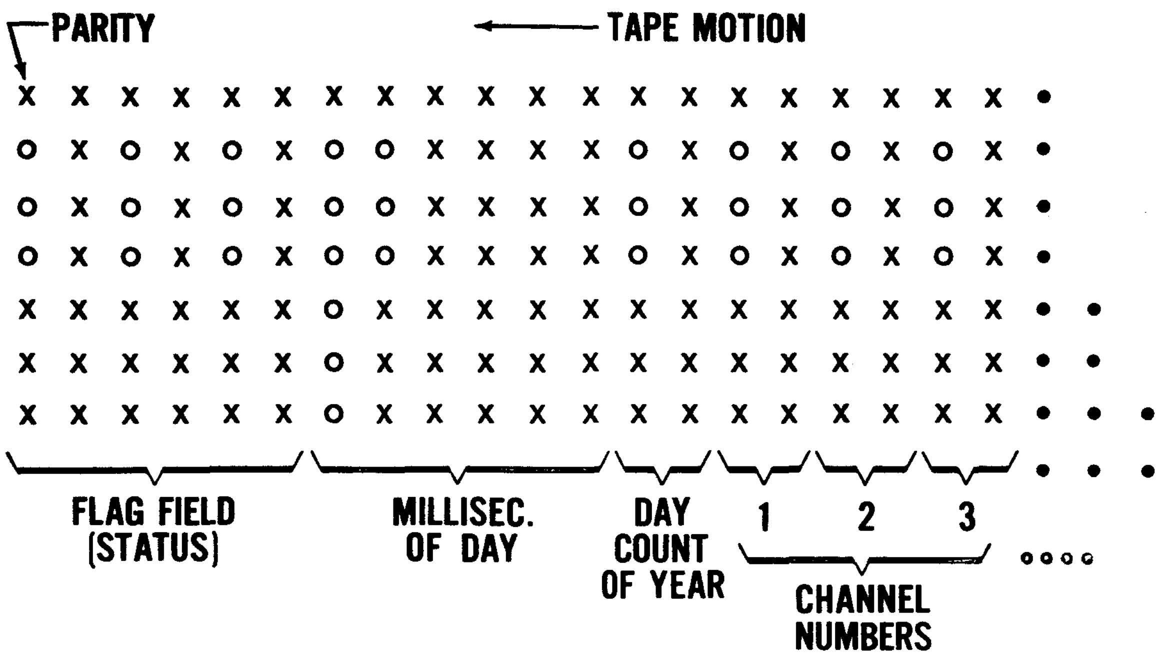


Figure 2–EGO Buffer Tape Format

The status field contains six computer tape characters, the time-of-day field contains six characters, etc. Two 6-bit tape characters are used for each telemetry data word, but three of the bits in each character pair are left blank. The time indicated will be the time of occurrence of the first bit of the first word of the frame. In the case of on-board stored data, this acquisition station time will be of no interest to the experimenters because the station time will not be related in a simple manner to the time at which the data were recorded in the spacecraft. Consequently, station time will not be placed in the time field for the on-board recorded data during the Phase I processing.

Phase II (illustrated in Figure 3) will be the processing of the buffer tapes to form the individual experimenter's tapes. This operation will use a Univac 1107 digital computer. Its ultimate outputs will be experimenter data tapes and an aspect housekeeping tape. The configuration of the computer is shown in Figure 4. It provides for simultaneous reading or writing on tape decks on three channels, thereby providing a total tape handling capability of 28 tape units. A large random access drum storage system with a capacity for 1.5 million words provides for quick access of huge volumes of data. Other on-line peripheral equipment include a high-speed printer, a card reader/punch,

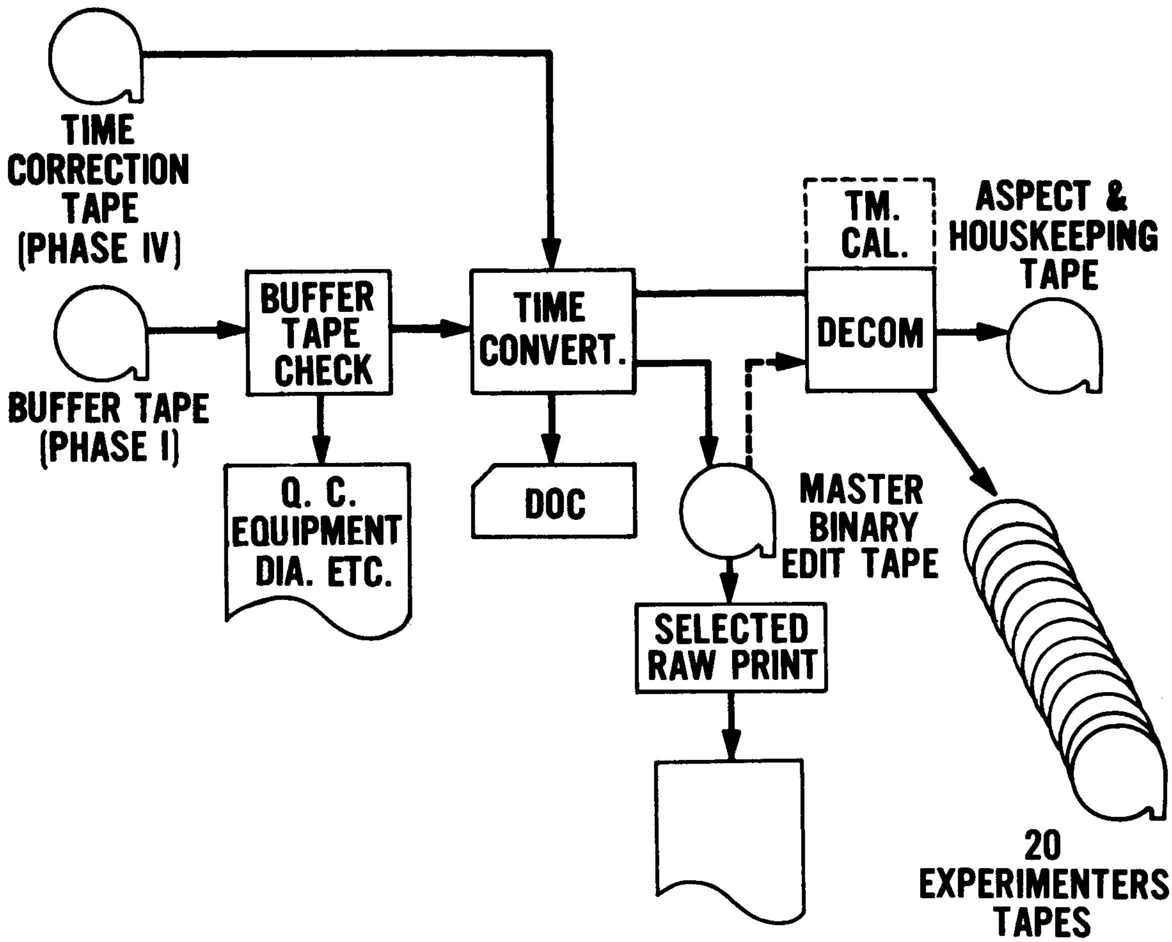


Figure 3–Data Processing – Phase II

paper tape reader/punch, and a console typewriter. The tape units and the peripheral equipment use a total of 8 input/output channels. The central processor has a 2-bank core storage with a total of 65,000 memory locations.

The basic word length for the 1107 computer is 36 bits. It has the additional feature of byte manipulation which permits handling of the data in bytes of 12 bits without time-consuming shift operations. This means a large saving in computer time when processing the short data words from EGO.

During the operation of Phase II the computer will check data quality as well as perform data decommutation. The computer will ascertain whether the data quality has deteriorated in the satellite or ground

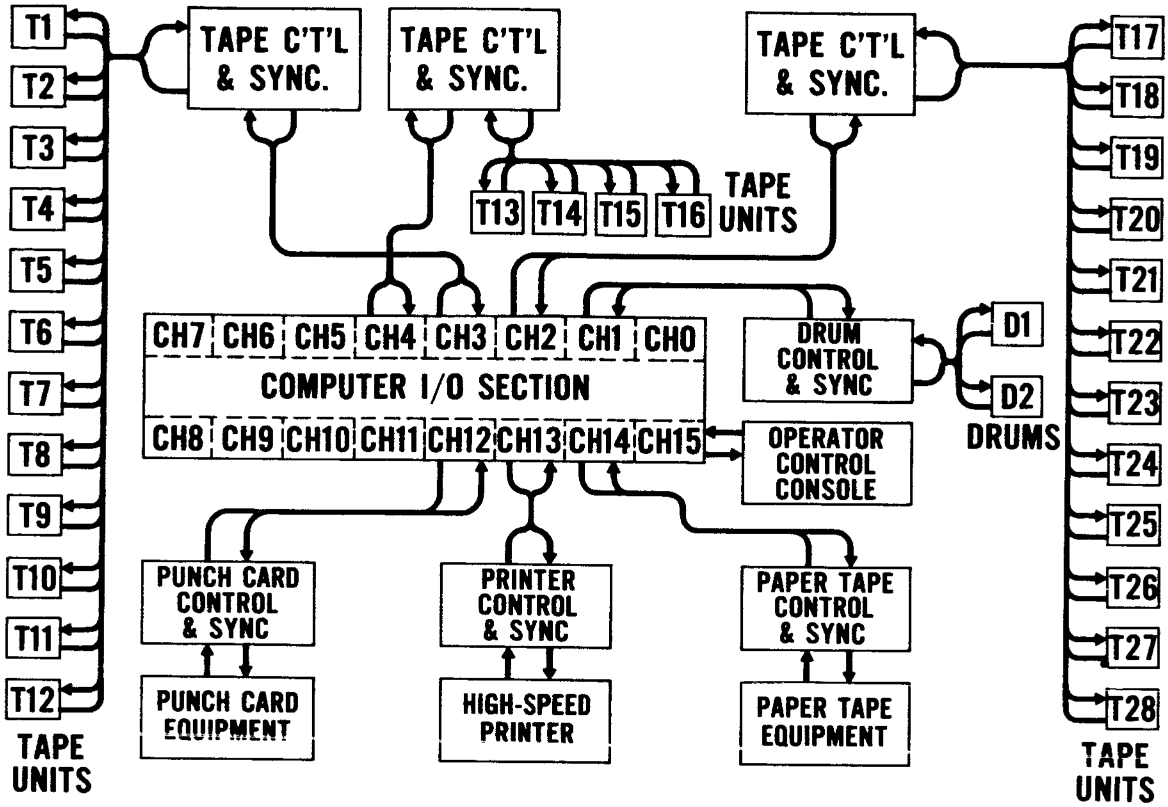


Figure 4—Goddard-Univac 1107 Computer Configuration

station telemetry links or in the Phase I operation. Multiple labels* in a file, record length, and frame length will be checked to verify the buffer tape format. Additional checks will involve the form of the data; the sync word will be checked for bit errors, the subcommutator count will be checked for proper sequencing, and data words will be checked to ensure that the first three bits of the 12-bit field are zero. A representative sampling of the analog channels will be checked to ensure that the first bit of the 9-bit field is zero. Additional checks will be made of certain channels in the frame which maintain at a nearly constant level.

This completes the buffer tape check portion of Phase II. The next step is the insertion of corrected universal time in the data format.

*A buffer tape label contains the satellite number, station number, date of reception at ground station, and station tape number.

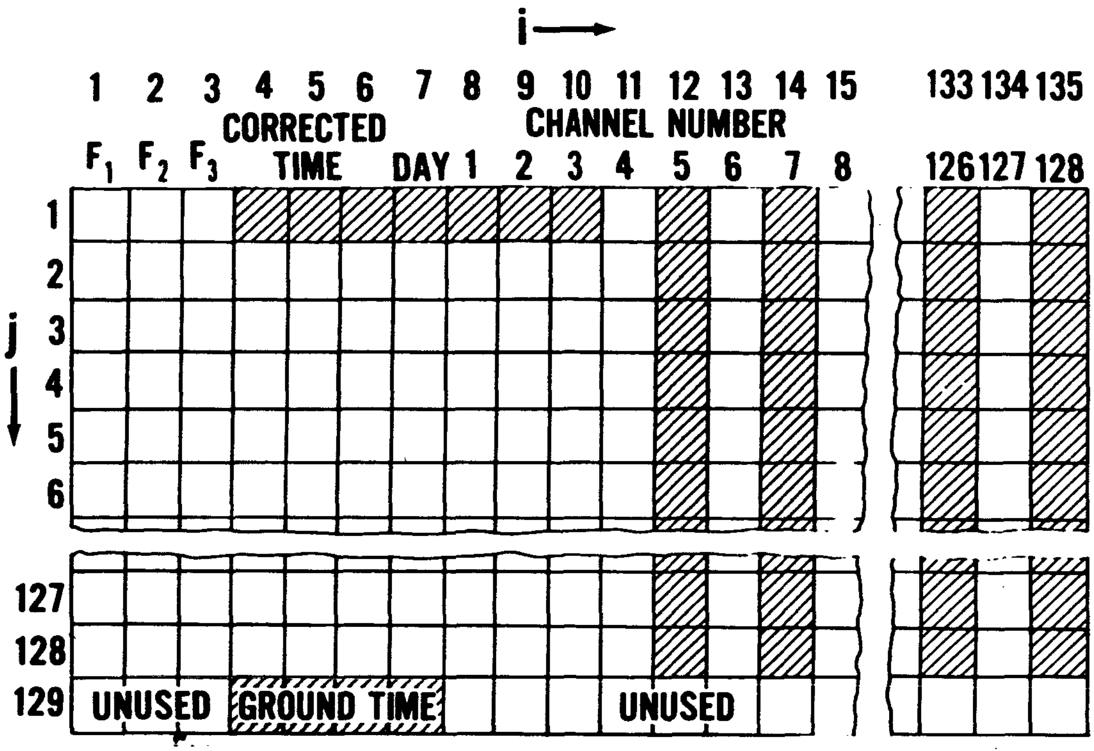
The task of correlating universal time with the data will be performed during the time-conversion portion of Phase II. A time-correction tape, generated in the Phase IV operation, will be used as one of the inputs to this operation. This tape will contain a lookup table which will list universal time as a function of the contents of the spacecraft-time word register (words 33, 34, and 35). In order to insert the time associated with a particular data frame, it will be necessary to examine the contents of words 33, 34, and 35, look up the corresponding universal time on the time-conversion tape, and insert this value in the time field. This scheme will provide an accuracy of about 11 milliseconds for 1000 b/s data. The time conversion process is discussed in Phase IV.

A master Binary Edit tape containing all data will be generated for further use by the processing personnel on an off-line basis.

The decommutation routine is the next step of the Phase II operation. Figure 5 illustrates the manner in which the data will be treated in the computer. A data matrix will be formed in which "i" will denote the column and "j" will denote the row. Each row will consist of three flag elements, three corrected universal time elements derived from spacecraft time in the Phase IV process, one day count of the year element, and the 128 data words from the main frame (i = 8 to i = 135). The first row will include subcommutator words One. The j in the matrix denotes a subcommutator word number. A value (i, j) designates a <u>word</u> in the telemetry format; a row represents a main commutator cycle or <u>frame</u>; and the entire matrix represents a subcommutator <u>sequence</u>. The ground-time box in the 129th row of the figure is also part of the configuration for real-time data. It is the ground time at the data-acquisition station which was associated with the beginning of word One of the first frame in the matrix. The box will be all zero for spacecraft on-board recorded data.

Following the formation of each matrix in the computer memory, after receipt of data for each complete sequence the decommutation process will extract selected portions to form a number of data tapes equal to the number of experiments on the spacecraft. The experimenter's data tape will include the elements which the experimenter has selected from this matrix. The elements may be arranged within the matrix may be ordered as the experimenters wish.

A special feature of this phase is a program generator which uses a FORTRAN type language to specify the elements of the matrix, and



DECOM [(j=1,1,1); (i=4,7,1)★(j=129,129,1); (i=4,7,1)●(j=1,1,1); (i=8,10,1)★
(j=1,128,1); (i=12,14,2)(i=133,135,2)]:

Figure 5–EGO Decommutation Scheme

the order they are outputted onto experimenter tapes. An example of a source language statement required to generate a program which will output the cross hatched elements in Figure 5 is shown at the bottom of that illustration.

The generation of the orbit-attitude digital tapes takes place in Phase III. An orbit tape and an aspect housekeeping tape are used as inputs to the program, as shown in Figure 6. The orbit-attitude tapes will contain the orbit and satellite attitude information in binary floating-point format, with 36 bits to a field. A label record will be located at the beginning of each tape file. The label record will contain the time covered, the time interval between sets (normally one minute), the day of the year at the beginning of the present orbit, the orbit number, the orbital elements, the sun vector data, the time of the noon-turn, the times of entering and leaving eclipse, and other data. For each minute,

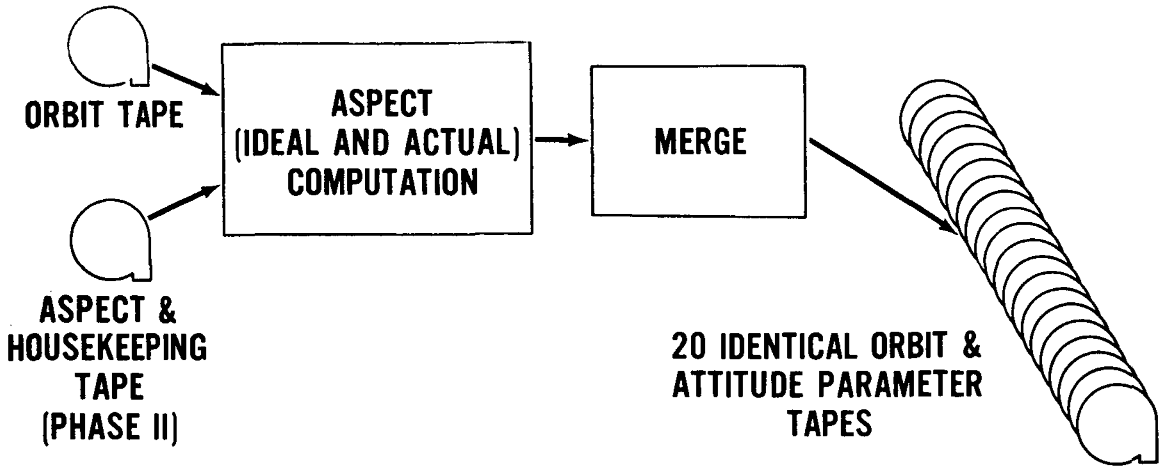


Figure 6–EGO Data Processing – Phase III

the following set of information will be listed: time in milliseconds of the day; position and velocity in celestial inertial coordinates; geographic coordinates of sub-satellite point; height above the geoid; ideal and actual main body, solar array and OPEP orientations; and true anomaly.

The Phase IV operation shown in Figure 7 will result in the generation of a time-correction tape which will permit the conversion of spacecraft time to corrected universal time. On the real-time data tapes, the spacecraft time and the acquisition-station time will be compared on a routine basis. Propagation delays in transmitting data from the satellite to the stations (about 0.4 sec at apogee) and of time from WWV (time standard station) to the receiving stations (0.058 sec for Woomera, Australia) will be taken into account, as well as any variations and discontinuities, if they exist, in the basic spacecraft clock system.

This time-correction tape will be used in the Phase II operation. Data time can easily be determined with an accuracy of 1 second if the available numbers are used and no additional computations are performed. Greater accuracy is possible. Figure 8 indicates the manner in which the spacecraft clock and commutator format are phased when the data system is operating at the 1000-bit-per-second rate. The 1-second pulses refer to the time at which one is added to the contents of the clock register. The contents of the clock register is telemetered once per main frame (words 33, 34, and 35). Sync words refer to the beginnings of the main frame. Each frame requires 1.152 seconds,

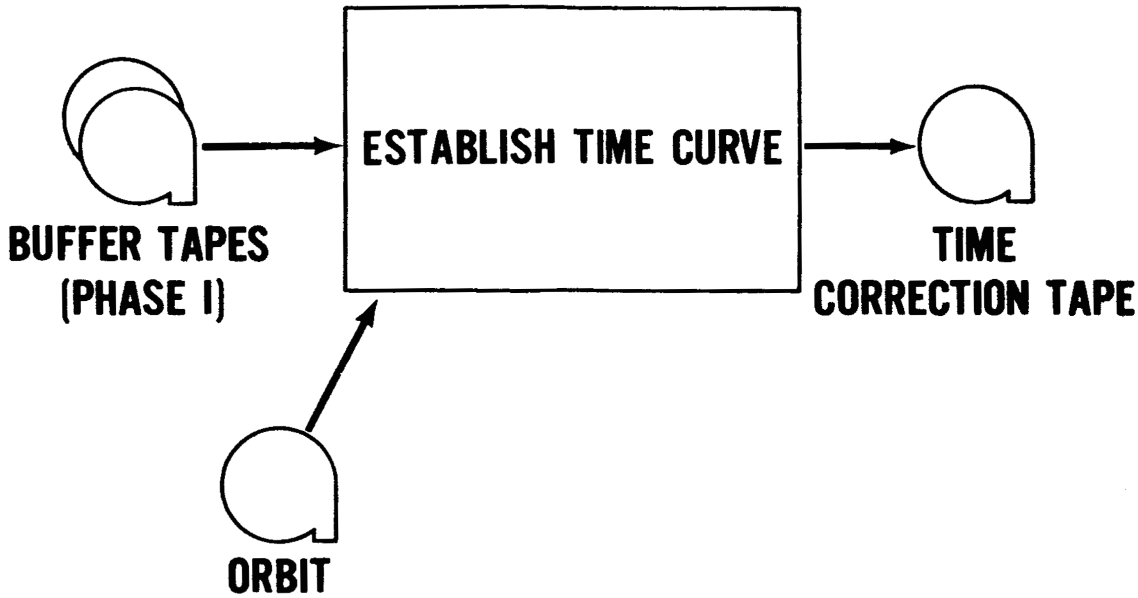


Figure 7–EGO Data Processing – Phase IV

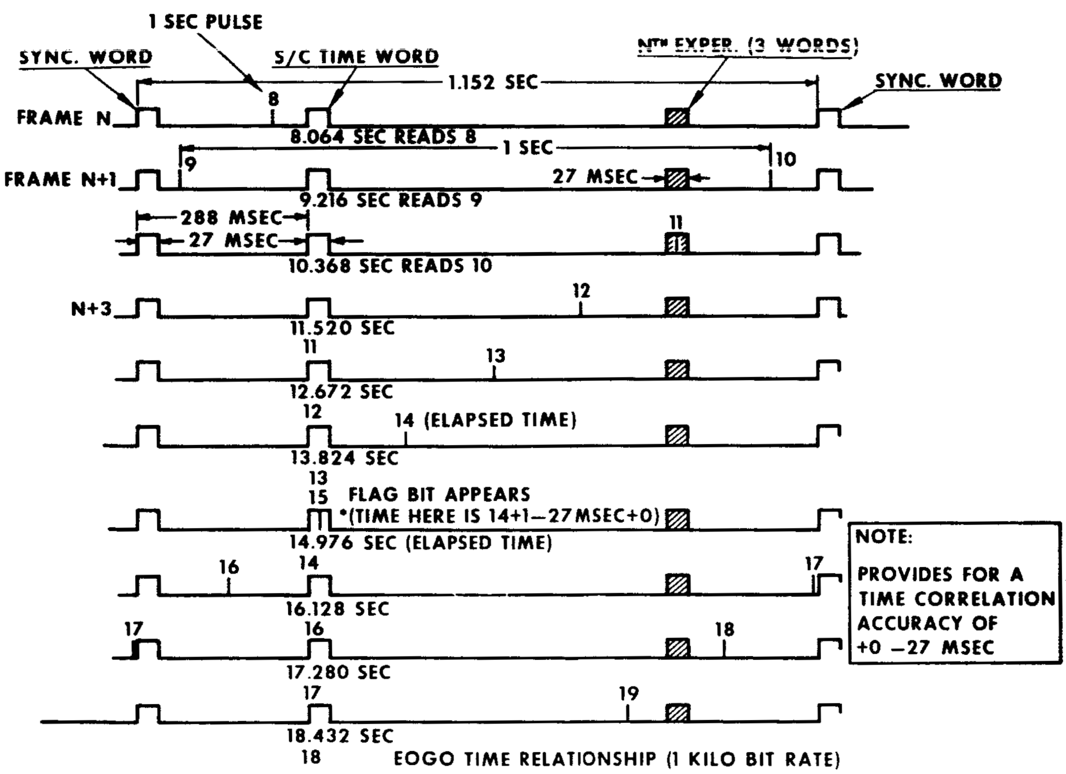


Figure 8–Time Insertion for EGO Stored Data

while the clock period is 1.000 second. A marker "one" is included in the clock word whenever the 1-second pulse occurs while the time words are being telemetered. Whenever this marker "one" is seen, the time being read at that instant (after the addition of 1 second) will be accurate to minus 27 milliseconds and plus zero.

Accuracy can be further improved by observing the phasing pattern. The number of frames between marker "ones" will follow a recurring 46, 46, 33, 46, 46, 33 .... pattern. Whenever the marker "one" occurs after the 33-frame period, the time will be accurate at that time to minus 11 milliseconds, plus zero.

Although this discussion refers to the stored data mode, the same logic applies to the real-time 8- and 64-kilobit data, and similar operations will be performed on them to provide high-accuracy timing for the real-time data.

EGO SPECIAL PURPOSE TELEMETRY DATA PROCESSOR

The special-purpose telemetry system on EGO will be used for the transmission of data from the Rubidium Vapor Magnetometer. The nature of this data is such that it is not well adapted to a PCM telemetry system in which it would have to be multiplexed with other signals. The signal is therefore transmitted separately on two of the five special-purpose telemetry channels. The magnetometer output signal is a noisy sine wave with a frequency proportional to the magnetic field intensity. The magnetometer frequency range is from about 10 cp/s for weak fields at apogee to frequencies above 100 Kc for the high fields near the earth at perigee. The response of the special purpose telemetry system is limited to 300 cp/s to 100 Kc, and so it is necessary to use two channels for the magnetometer signal. Channel No. 1 will be modulated by the signal taken directly from the magnetometer and will handle magnetometer frequencies between 300 cp/s and 100 Kc. Channel No. 2 will have a 40 Kc subcarrier which will be phase-modulated by the magnetometer signal for frequencies between 10 cp/s and 600 cp/s.

The special processor for the EGO magnetometer data is outlined in Figure 9. The recorded telemetry signal, the ground station time signal, and the station standard frequency are obtained from the reproduce analog tape deck. The station standard frequency will be either 1 Kc, 10 Kc, or 100 Kc. The tape deck can be made to reproduce the signals at either 1, 2, 4, 8, or 16 times the recorded speed, selectible by pushbutton control.

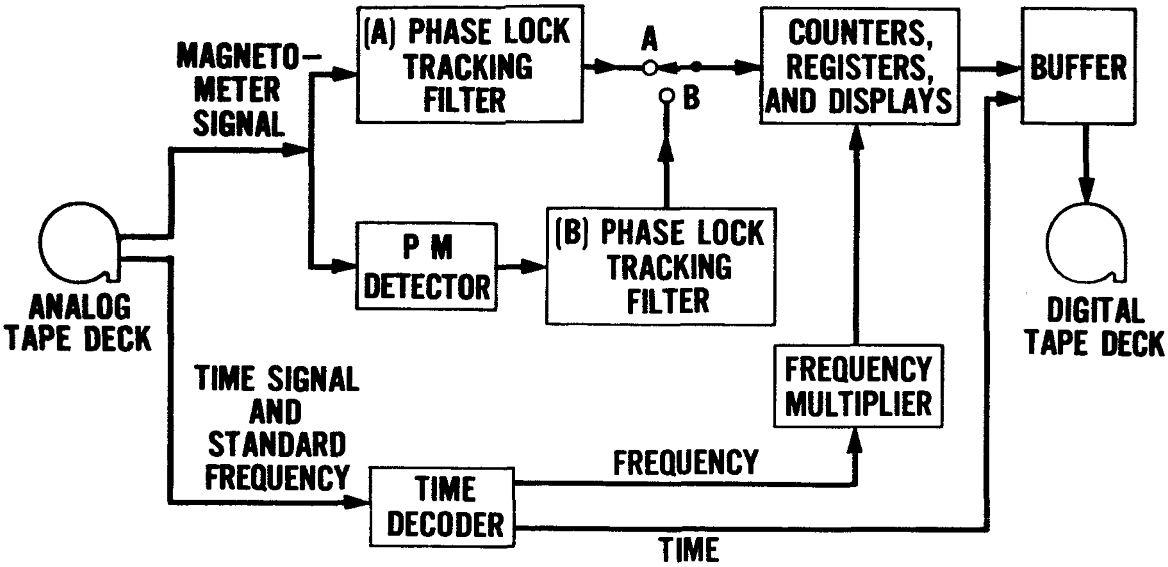


Figure 9–Special Data Processor for EGO Magnetometer

When processing the direct magnetometer signal (channel no. 1) the "A" phase lock tracking filter is locked to the noisy magnetometer telemetry signal, and the output of the tracking filter is a relatively clean signal which is phase-locked to the magnetometer signal. The frequency of this clean signal is measured in the counter unit. The frequency is determined by measuring the number of cycles of the signal in a period of time, which can be selected by means of a set of switches on the control panel. The range of selection is 1 millisecond to 9.999 seconds. The standard frequency, extracted from the analog tape signal by the time decoder, is multiplied to 5 Mc/s to be used for the timing in the frequency measuring unit. By using this recorded standard frequency in this manner, compensation is obtained for effects of tape recorder wow and flutter. Specifically, a counter is started counting cycles of the multiplied standard frequency at a zero crossing of the tracking filter reproduction of the magnetometer signal. The counter is turned off at the second integral signal cycle after the preset time is reached. The number of signal cycles in this period is also counted. The ratio of these two counts gives the frequency of the magnetometer signal. At the shortest time period, the resolution is limited to one cycle of the 5 Mc/s timing waveform, or 1 part in 5000. At the longest period the resolution is approximately 1 part in 5×10^7.

When processing the channel No. 2 signal consisting of the subcarrier modulated with the magnetometer signal, the subcarrier is demodulated in the phase-locked PM detector. The resulting noisy low frequency magnetometer signal is fed into the "B" phase lock tracking filter. The output of the tracking filter is sent to the frequency measuring counters through switch position B.

The magnetometer frequency data from the counter registers are put into the buffer where they are merged with ground station time from the time decoder and written on a digital tape in computer format. The time decoder, buffer and digital tape unit are identical to those in the EGO PCM data processor described earlier, and serve similar functions in the special magnetometer processor.

OPERATING TIME

The Table 1 estimate of the amount of data to be acquired from EGO has been used to predict the amount of PCM processor and 1107 computer time which will be required for EGO data processing. In establishing such predictions, many factors other than machine speed were considered such as operator efficiency, down time, tape deck loading time, etc.

During the first month the Phase I PCM processor time will average 18 hours per day, and for the rest of the EGO life the average processor time will be 12 hours per day. Two PCM processors have been built in order to provide the extra capacity for alert periods when the satellite is operated at the highest bit rate, and to provide sufficient redundancy to prevent equipment breakdown from slowing down the processing operations.

The 1107 computer time required for Phases II, III, and IV is predicted to be 22 hours per day for the first month and 14 hours per day for the remaining life of the satellite. It should be noted that Phase II, III, and IV do not include any true data reduction or analysis of the data. These data processing operations produce a set of digital tapes for each experimenter. These tapes contain all of the experimenters' raw data plus the support data. Each experimenter will be responsible for the reduction and analysis of his data. Four of the EGO experimenters from the Goddard Space Flight Center have arranged for data analysis computations on the 1107 computer. It is estimated that these computations will require three additional hours of computer time per day.